Transdisciplinary Engineering: A Paradigm Shift
C. Chen et al. (Eds.)

doi:10.3233/978-1-61499-779-5-329

Reflecting Meaning of User Experience：Semiotics Approach to Product Architecture Design

Xi ZHANG[a], Fei HU[a,1], Kun ZHOU[a] and Keiichi SATO[b]
[a] *School of Arts and Design, Guangdong University of Technology*
[b] *Institute of Design, Illinois Institute of Technology*

Abstract. Research in product architecture design has been addressing user related issues such as usability and affordance in order to enhance product efficiency, accessibility as well as safety. Yet, issues related to the question how people adopt, position and use new products in different environments, situations and modalities of use have not been well addressed. This paper examines how Semiotic Approach to Product Architecture Design (SAPAD) can be applied to the design of spatial organization of functional systems with an example of kitchen that embodies and reflect functional, cultural and lifestyle requirements of different users. First, the Semiotic Ladder framework introduced by Stamper that addresses six levels of interpretive mechanism was applied to the user observation data in order to understand how users interpret individual components and subsystems and to identify structure of meaning and values formed by the user through the usage process. Then the structure was used as a basis for developing the system architecture.

Keywords. Product Architecture, Semiotics, SAPAD, Signification, Culture

Introduction

The concept of product architecture (PA) was introduced by Ulrich and Eppinger (1995) [1] as the scheme by which the product functions are allocated to physical components, aiming to define the basic physical building components. Ulrich (1995) [2] articulated five potential application areas of product architecture: 1) product change; 2) product variety; 3) component standardization; 4) product performance; 5) product development management. Since then, various researches have been developing the foundation and applications of product architecture from engineering design perspectives (Wood, Stone Fadel, Meyer, etc) [3].

Recent advancement in ICT, embedded technology and robotics have been becoming more pervasive and ubiquitous in our daily living and work environments. This enables us to access more functions and information for assisting our activities to become more efficient, safe and pleasurable. On the other hand, new systems have been introducing complex technological infrastructure that imposes us new orders in every aspect of our lives. This implies that products, systems, services, and business need to be coherently designed and operated across all aspects of users' daily lives. In order to

[1] Corresponding Author, Mail: philhu2002@hotmail.com

address such issues, the concept of human-centered product architecture was introduced as a methodological foundation for HCD (Teeravarunyou and Sato 2001, Galvao and Sato, etc.) [4] [5].

Although the importance of user-centric approach has been widely recognized in system development and business, little research has been focused on system usage process as an intensive knowledge generating process critical for successful system design and implementation. For example, the adoption and usage of a new system requires knowledge of interpreting the system properties, knowledge of positioning the system in the existing system of work environments such as physical organization, social organization, information, activities and cultural norms, and knowledge of developing meaning and values for justifying the acceptance of the system and further sustain the process of the evolving system use.

This research focuses on the concepts of signification and experience in the system usage process as a basis for designing product architecture. In order to incorporate fundamental mechanisms of system usage processes and map them on to system architecture design, Semiotic Approach to Product Architecture Design (SAPAD) [6] [7] is applied for bridging user observation data and the interpretation of the user information onto system architecture design. A case study with cooking activities in a kitchen space was developed to demonstrate the analysis of user significations that enables a new approach to developing user requirements and designing system concepts.

1. The SAPAD Framework

In order to understand complex knowledge generation process and human interactive behavior based on the meaning generation in the system usage process, SAPAD framework introduced a semiotic modeling approach. In the semiotics model by Peirce (Peirce,1867) [8], both human behavior and system behavior can be considered as "Media" or "sign" as the first dimension representing the concept of "Object" i.e. the second dimension. The object can be any referable entity such as physical objects, intentions, information, concepts, and actions. Signification produces "Interpretation" of "sign", the third dimension. Pierce's semiotics model explains the signification mechanism at three levels, syntactics, semantics and pragmatics in the linguistic terms.

Semiotic Ladder Model by Stamper introduced six levels of the signification mechanism corresponding to the ontological structure of semiotic processes in organization and information systems design (Stamper, Liu, 1996, 2000) [9] [10]. The six levels of the semiotic ladder are defined as shown in Figure 1) Physical level is about physical attributes which are related to enabling elements of functions such as material, signals, traces and physical distinctions; 2) Empiric level of signification is about "how" to connect the subject with object. It is related to construction of logic, which focus on the operation and control of object, and the users' experience such as mode, way, noise, redundancy and efficiency; 3) Syntactic level of signification is about "how" to connect with each other between the function modules; 4) Semantic level of signification is about "why" to interact between individual and object, which relates to emotional experience and focus on emotion, character and persuasiveness of object, such as theme, expression, and intention; 5) Pragmatic level of signification is about "how" to communicate in interactions, which focuses on sub-culture and group identity; 6) Social level of signification is about social attributes in the interaction, which focuses on value and ideology and relates to beliefs, expectation, commitment, contract, law and cultural convention.

As "signification" manifests the six levels of hierarchical structure, the dimension of "object" can be divided into four levels: assembly, object, unit and component (Ulrich,1995) [2]. Component includes the activity of all products that was applied for completing the task in the process. Every product can be divided into multiple assemblies, each assembly into units with different behavior or functions and every unit is composed of many components.

The dimension of "Behavior" can be also explained with a hierarchical structure for example, with four levels, activity, process, action and operation (Leont'ev,1978) [11] [12]. SAPAD chose the term "activity" and *i*th-level action for multiple levels since different disciplines have different definitions of terms representing levels of actions.

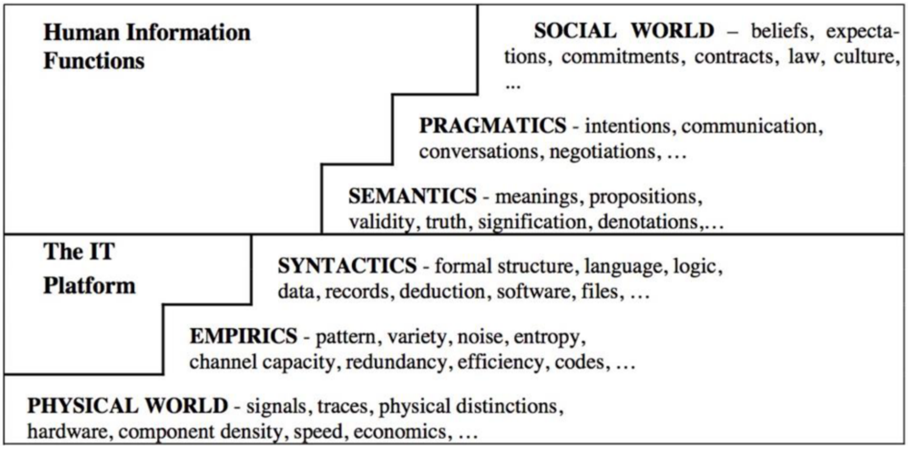

Figure 1. Stamper's semiotic ladder.

2. SAPAD for Bridging User Research and Product Architecture

The process of SAPAD consists of three phases with eight steps. In order to effectively follow through the SAPAD process, templates and tools for information acquisition and analysis have been developed.

Phase 1: Behavior observation and analysis

This phase is composed of the following three steps: 1. Object analysis 2. User observation and 3. Behavior analysis.

Object Analysis produces an architectural description of a product or a system that represents its topological configuration of subsystems and components. First, components (function carriers) and interactions (functional dependency) between them are identified. Then, a hierarchical structure of components is constructed corresponding to different levels of functional modules based on degrees of functional and structural dependency (Ulrich, 1995) [1]. This step can be done after Step 2 or 3 depending on the nature of the project.

User Observation intends to capture the actual situation of product or service system usage. It attempts to capture the usage process, users' states, various environments such as physical, social and cultural, and relevant objects by videos, photos, notes and other means. Questionnaire survey and interviews before and/or after the observation can be also used in order to provide enough information for deeper understanding of the user behavior.

Behavior analysis. to make behavior hierarchy and layer behavior according to activities, processes, action and operation, outlining the structure of the user's behavior and related items clearly.

Phase 2: Signification analysis and construction.

Excavating the under meaning of the user's behavior by analyzing physical level, syntactic level, empiric level, semantic level, pragmatic level and social level.

Signification construction. Making sure of the accuracy and availability of signification through interviewing user again, at the same time, reconstructing signification cluster, insight into the crucial meaning of behavior and core values of the user and possible design directions by hierarchical clustering on the DSM.

Phase 3: Product construction and design:

Signification-Objects Mapping. Combining with 4, 3, 2 to determine the mapping among and between signification cluster (four levels) and things, defining the key objects of signification.

Product architecture bases on signification cluster. Assigning the number to the relationship of object signification base on {0, 3} Brin logic and outputting new units, new products or new groups by symmetric matrix.

Design opportunities. Introducing new function and new architecture of the product, legible design opportunities and concrete paths for innovation based on the new configuration of components, units, objects and assemblies.

3. Case Study: Cooking Activity in a Home Kitchen in Central China

3.1. Step1 Observation and User Behaviour Analysis

This case study observed and examined the lunch-cooking activity of a 60-year-old retired male in a small home kitchen located in a large city area in central China. The observation revealed that the primary cooking activity is composed of six processes: P1, cleaning ingredients; P2, cutting/preparing ingredients; P3, cooking; P4, serving food; P5, cleaning cookware and tableware; and P6, storing cookware and tableware. These six processes can be further divided into thirty-one actions in the same way as Hierarchical Task Analysis (HTA) [12]. For example, the cleaning ingredients process includes taking out ingredients, washing ingredients, disposing garbage.

3.2. Step 2 Behaviour-Signification Mapping and Signification Structure

From the user observation and other studies about user engagement in the cooking process, signification factors on the user's behavioral elements were elicited. In syntactic level, seven signification clusters were identified: 1) disposing garbage 2) arranging ingredients processing area; 3) cooking with heat; 4) washing tableware and restoring dishes; 5) restoring cooking utensils and pots; 6) restoring oiler and rice container; 7) restoring seasoning boxes and canister.

In empiric level, eight signification clusters were identified: 1) easy access to cooking utensils and condiments: easy to pick cooking utensils, oil container, seasoning canisters, ingredients, and easy operation; 2) preventing corrosion and plasticization in high temperature; 3) easy access to ingredients and rice: easy to pick ingredients, rice, smooth operation, object placed nearby; 4) preventing sink blockage; 5) large operating space; 6) keeping rice container in dry place; 7) placing a cutting board easily; 8) keeping kitchen clean: organize cookware and utensils neatly, keeping kitchen clean, and keeping hygienic. It shows that empiric level reflects users' general guideline for handling and controlling experience during cooking process. For example, user generally places the cooking utensils, spices and other objects nearby each other based on their cooking experience for easy and fast task execution.

In the semantic level, five clusters were defined: 1) healthy diet; 2) less oil and mild taste; 3) safe and clean-ingredients; 4) tableware hygiene and preventing odors; 5) comfortable and pleasurable cooking. From user's perspective, the core of semantic level is "healthy regimen". Through cluster analysis of symmetric matrix of the sematic level, user's expectations can be found in six particular areas: tableware hygiene, comfortable operation, light diet, health, food safety and nutritional balance.

In the pragmatic level and social level, two signification clusters were identified: 1) emotional expression; 2) cooking and eating patterns: regional cooking tradition, family diet styles and regional diet. These levels emphasize the user's value and ideology. For example, people express their feelings and caring for their families through cooking.

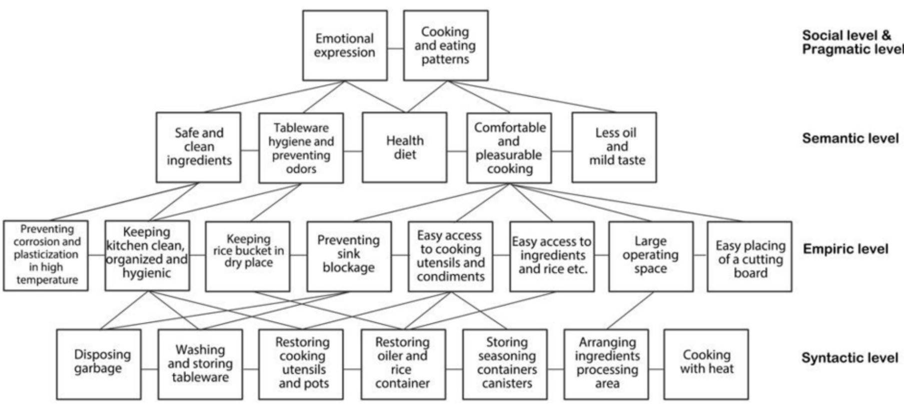

Figure 2. Signification module of user cooking behavior.

Furthermore, all signification clusters in different levels are reconstructed as show in Figure 2. It is obvious that the core concern in the cooking activity includes health, emotional expression and cultural tradition in regional diet.

3.3. Step3 Signification-Object Mapping

According to the eight signification clusters mapped to actions and objects, in empiric level, the key objects included seasoning canister, oil container, cooking surface, ingredients, plates, refrigerator, sink, garbage can, cutting board and faucets. These objects are usually clustered together in the kitchen by the furnishing configuration and the user's preference to ensure the operability and comfort for the cooking activity as shown in Table 1.

Table 1. Mapping analysis of object-signification in empiric Level.

Signification clusters	Actions	Related objects	The key objects
Easy to pick caster, easy to pick cooking tools, easy to pick oiler, easy to pick seasoning ingredients, easy operation	P3.1: pouring the seasoning to seasoning boxes	cupboard, seasoning, seasoning boxes, placing units	Seasoning containers
	P3.7: seasoning	seasoning containers, castors， pan, spatula, placing units	Seasoning containers
	P3.4: pouring oil	oiler, placing units, frying pan	Oiler
Preventing corrosion, plasticization in high temperature	P6.3: Tidying countertop	operation table	Operation table
Easy to pick up ingredients, easy to pick rice, smooth operation, object placed nearby	P1.1: getting ingredients	ingredients, refrigerators, trash bags	Ingredients
	P2.5: placing the ingredients to the plate	plate, ingredients operation table	plates
	P2.6: placing leftovers to refrigerator	ingredients, refrigerator	refrigerator
Preventing sink blockage	P5.5: cleaning sink	sink, garbage can, rag	sink
	P1.3: throwing away rubbish to garbage can	sink, rubbish, garbage can	garbage can
Enough operating space	P2.4: cutting ingredients	cutlery, chopping board, ingredients, operation table	operation table
	P2.5: placing the ingredients to the plate	ingredients, plates, operation table	operation table
Keeping rice container in dry place	P1.1: getting ingredients	ingredients, refrigerator, trash bag	ingredients
Placing a cutting board easily	P2.1: placing chopping board	chopping board, console operation table, placing station	chopping board
	P2.7: washing the chopping board and knives	chopping board, cutlery, faucet, sink, rag, chopping board, placing units	chopping board
Organizing countertops, keeping kitchen clean, preventing bacteria growth	P5.2 ：throwing away rubbish	rubbish, garbage can	garbage can
	P5.3: processing the leftovers	leftovers, top drawer, bowls, refrigerator	refrigerator
	P5.4: cleaning tools	faucet, sink, cleaner	faucet

3.4. Step 4 Product Architecture based on signification

The degree of signification relations between objects are evaluated by four values (0, 1, 2, 3) in Likert scale where 0 for no signification, 1 for some signification, 2 for strong signification and 3 for very strong signification. The result was formatted as a DSM and Bertin sort method (Ref) was used to identify object clusters. Bertin sorting uses a series of permutations of rows and columns in order to form clusters of the matrix elements with strong relations visually represented along diagonal matrix cells. [13] [14]

In Empiric level, ten clusters of objects were identified and named as follows: 1) ingredient processing clusters includes ingredients，cooking surfaced, cutting tool and chopping boar; 2) garbage processing clusters includes garbage, garbage can and garbage bag; 3) cookware cluster includes oil container，cooking utensils and frying pan; 4) cleaning cluster includes detergent, wash basin, faucets and sink; 5) tableware & food preservation cluster includes bowls, plates， eating utensils，refrigerator， leftovers， drawers and cabinets; 6) placing clusters includes seasoning bottles, spices，dry seasoning container and placing surface, as show in Figure 3.

	Ingredients	Cooking surface	Chopping board	Cutting tool	Garbage	Garbage can	Garbage bag	Oil container	Frying pan	Cooking utensils	Sink	Faucets	Detergent	Wash basin	Bowls	Eating utensils	Plates	Leftovers	Refrigerator	Drawers	Cabinets	Dry seasoning container	Seasoning bottles	Spices	Pacing table
Ingredients	3	3	2	2	1	1	2	1	3	0	0	3	0	2	1	1	1	3	3	0	0	0	0	2	3
Cooking surface	3	3	3	3	2	2	0	0	2	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	1
Chopping board	2	3	3	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Cutting tool	2	3	2	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Garbage	1	2	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Garbage can	1	2	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Garbage bag	2	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oil container	1	0	0	0	0	0	0	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Frying pan	3	2	0	0	0	0	0	3	3	3	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2
Cooking utensils	0	0	0	0	0	0	0	1	3	3	0	0	1	1	0	0	1	0	0	0	0	0	0	1	1
Sink	0	1	0	0	0	0	0	0	0	0	3	3	2	3	0	0	0	0	0	0	0	0	0	0	0
Faucets	3	1	1	1	0	0	0	0	0	0	3	3	1	3	1	0	1	0	0	0	0	0	0	0	0
Detergent	0	0	0	0	0	0	0	0	1	1	2	1	3	3	2	1	1	0	0	0	0	0	0	0	0
Wash basin	2	2	0	0	0	0	0	0	1	1	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0
Bowls	1	0	0	0	0	0	0	0	0	0	0	1	2	2	3	3	3	2	2	1	2	0	0	0	1
Eating utensils	1	0	0	0	0	0	0	0	0	0	0	0	1	2	3	3	3	2	1	2	2	0	0	0	2
Plates	1	0	0	0	0	0	0	0	0	1	0	1	1	2	3	3	3	2	2	2	2	0	0	0	2
Leftovers	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	3	3	0	0	0	0
Refrigerator	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	2	3	3	3	3	0	0	0	0
Drawers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	3	3	3	3	1	0	0	0
Cabinets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	3	3	3	3	1	2	0	1
Dry seasoning container	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	3	3	3
Seasoning bottles	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	3	3
Spices	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3
Pacing table	3	1	1	1	0	0	0	3	2	1	0	0	0	0	1	2	2	0	0	0	1	3	3	3	3

Figure 3. A Weighted DSM Representing Relations between Physical Components in Empiric level.

Ten object modules (clusters) were identified in Semantic level: 1) ingredients; 2) placing surface; 3) seasoning storage; 4) bowl storing; 5) refrigerator; 6) eating utensil; 7) cookware; 8) cooking template; 9) garbage processing; 10) cleaning. In the pragmatic and social level, nine object modules were identified: 1) ingredients; 2) cookware; 3) cooking; 4) eating utensils; 5) steamer; 6) food storage; 7) gas stove; 8) the seasoning storage; 9) rice storage. The clustering shows a variety of possibility of grouping the items. Based on the signification patterns, 11 function modules of cooking activity were determined after comprehensive analysis: 1) food processing; 2) cookware; 3) cooking; 4) tableware storage 5) cleaning; 6) garbage processing; 7) dining utensil; 8) refrigerator placing; 9) seasoning storage; 10) rice storage; 11) others. Figure 4 shows more detailed modules hierarchy of the kitchen system.

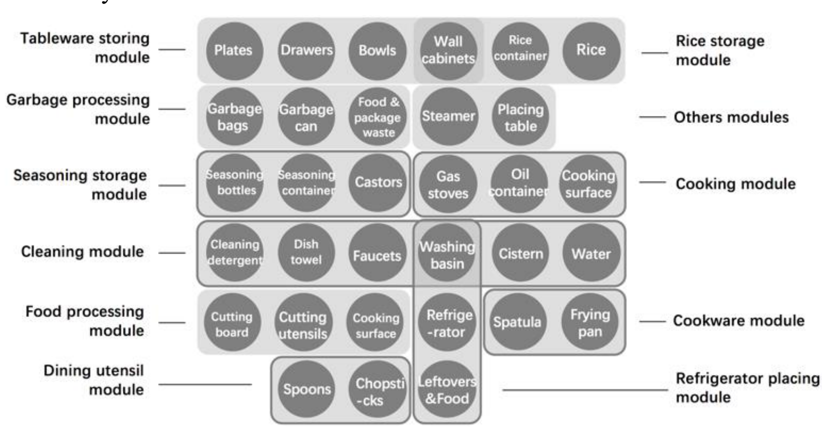

Figure 4. Identification of product modules of the kitchen.

3.5. Step5 Design Opportunity and Product Development

The clustering of the product modules allows the reconfiguration of the cooking activity organization by providing a conceptual basis. At present the cooking activity structured simply a combination between sets of cabinets and the user's conception of the various cooking functions. In this example, the three types of layout configuration, "linear" type, "L" type and "U" type as shown in Figure 5 were selected as potential solutions for the case out of many possible layout patterns.

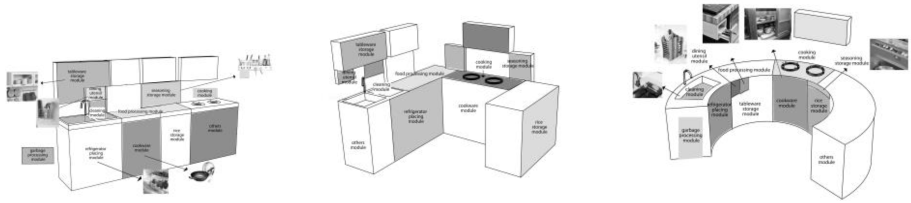

Figure 5. Identification of product modules of the kitchen.

4. Discussion

In the case study, the concepts of health, emotional expression, personal cooking and eating styles are identified as a key meaning factors. Although cooking can be a pleasurable activity for some people but majority of the people living by themselves consider it as burden in their daily lives. Cooking activity becomes more pleasurable if it is motivated by the sense of compaction to family member and friends.

The introduction of semiotics ladder provides effective framework for analyzing observation data with its six categories of signification. Using semiotic ladder, SAPAD framework can capture user knowledge from a more comprehensive range and represent them in more structured forms.

5. Conclusions

Local knowledge, the diversity of different cultural background and historical evolution process lead the different understanding to knowledge interpretation in different situations. Therefore, the concept of "kitchen" is generated in the local culture and must be defined by combining with its contemporary usage patterns and user background. We also need to be aware that the personal knowledge embodied in the Empiric level and Semantic level information is the important clue of local knowledge that implies a range of personal and market level adaptability addressed in the further architectural decisions.

The overall research goal is to construct a methodological frame for applying semiotic approaches to model users and product relations as a basis for the product architecture formation. In order to achieve this goal, functional signification of the physical and syntactic levels, or individual experience and emotion derived from the empirical and semantic levels, or socio-cultural signification derived from pragmatic and social levels, are translated into design knowledge that can be converted into product specification. Local knowledge can be translated into specific functional descriptions or user needs because it represents solutions when local users encounter problems and it can be passed to other local users when encountering similar problems. Local knowledge can be described as reasonable association with objects, process and usage background.

The future challenge of this research is to integrate insights from multiple system views including semiotic models, operational process models and affordance models as well as other technical views into a coherent architectural configuration. A well-formed architectural solution should provide a flexible design platform for developing further detailed specifications. Most importantly, the further development of this approach needs to address the complexity and dynamics of technological and social changes that the product needs to be positioned and operated as a part of larger systems.

Acknowledgement

This study was partly supported by National Social Science Fund on ‘Research on Experience of Community-Elderly Care Based on Medical Care-Pension Integration’ (No.15BG088).

References

[1] K. T. Ulrich and S.D. Eppinger, *Product design and development*, MacGraw-Hill, New York,1995.
[2] Ulrich K. T., The role of product architecture in the manufacturing firm, *Research Policy*, Vol. 24, 1995, pp. 419-440.
[3] R.B. Stone, K.L. Wood and R.H. Crawford, Using Quantitative Functional Models to Develop Product Architectures, *Design Studies*, Vol. 21, 2000, No. 3, pp. 239-260.
[4] S. Teeravarunyou and K. Sato, User process based product architecture, In: *Proceedings of the 2001 World Congress on Mass Customization and Personalization*, Hong Kong, 2001, pp.1-10.
[5] A. Galvao and K. Sato, Human-Centered System Architecture: A Framework for Interpreting and Applying User Needs, In: *ASME Design Engineering Technical Conference Proceedings*, Cleveland, 2004, pp. 487-495.
[6] F. Hu, K. Sato, X. Zhang, et al., Semiotic basis for designing product architecture, In: *the 19th International Conference on Engineering Design (ICED13),* Seoul, 2013, pp. 19-22.
[7] F. Hu, X. Zhang, K. Sato et al., Human-centred Product Architecture from UPPA to SAPAD, In: *International Conference on Sustainable Energy and Environmental Engineering,* Bangkok, 2015, pp. 112-115
[8] C.S. Peirce, *The essential Peirce: selected philosophical writings (1867-1893)*, Indiana University Press, 1992.
[9] R. Stamper, Signs, Norms, and Information Systems, *Signs of Work*, Walter de Gruyter, Berlin, Germany,1996, pp.349-397.
[10] K. Liu, *Semiotics in information systems engineering*, Cambridge University Press, 2000.
[11] R.D. Vieira, G.J. Kelly and S.S. Nascimento, An activity theory-based analytic framework for the study of discourse in science classrooms, Author, Article title, *Ensaio Pesquisa em Educação em Ciências,* Vol. 14, 2012, pp. 13–46.
[12] N.A. Stanton, Hierarchical task analysis: Developments, applications, and extensions, *Applied Ergonomics,* Vol. 37, 2006, pp. 55–79.
[13] J. Bertin, *Graphics and graphic information processing*, de Guyter, Berlin, 1981.
[14] J. Bertin, *Semiology of Graphic: Diagrams, Networks*, University of Wisconsin Press,1983.